Dual-Wavelength Vertical-Cavity Surface-Emitting Laser Arrays Fabricated by Nonplanar Wafer Bonding

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Abstract: A dual-wavelength 1550nm and 1530nm VCSEL array is fabricated using two separate and distinct active regions integrated on a common mirror by nonplanar wafer bonding.

WDM systems and next-generation high-speed optical networks require single chips with multiple wavelengths and integrated optical and electrical functionality. Fabricating these highly versatile chips requires wafer-scale integration techniques capable of combining different semiconductor structures in the surface plane of the wafer without degrading the performance of the devices. One such technique is nonplanar wafer bonding [1]. Nonplanar wafer bonding uses a single wafer bond step to transform epitaxial structures into lateral epitaxial variation across the surface of the wafer. In this paper we present the first successful application of this technique in the fabrication of a dual-wavelength vertical-cavity surface-emitting laser (VCSEL) array operating at 1550 and 1530nm. The technique should be extendable to integration across the C, L and S bands, and to 1310 nm VCSEL integration as well.

The nonplanar wafer bond used in the fabrication of this device begins with two strained multi-quantum-well long-wavelength VCSEL active regions grown vertically on an InP wafer and separated by an etch-stop layer. The active regions have optical cavity lengths of 2.5 wavelengths at 1550 and 1530nm and have photoluminescence peaks at 1530nm.

The wafer surface is etched with a step shaped profile to reveal a different active region on each step level. The backside of the wafer is etched to have a profile complimentary to the step-etched active region side of the wafer, as shown in Fig. 1(a). This substrate thickness adjustment etch is designed to yield an identical substrate plus epitaxial film thickness at each lateral point on the wafer. The lateral offset between the front side and backside step edges determines the distance over which the substrate and epitaxial layers must accommodate the deformation. The nonplanar wafer is direct wafer bonded to a 40-period AlGaAs distributed Bragg reflector (DBR) grown on a GaAs substrate. The original InP growth substrate is removed, leaving the active regions attached to the transfer substrate as depicted in Fig. 1(b). The excess active region material and the deformation accommodation regions are removed, revealing a different active region at each lateral position on the AlGaAs mirror as represented by Fig. 1(c). A second, 27-period, AlGaAs DBR is bonded by traditional semiconductor-direct bonding [2] to create the structure shown in Fig. 1(d).

Fig. 1(d) shows a cross-section schematic of the final dual-wavelength VCSEL array structure. The array is optically pumped with a 980nm pump laser, a technique that has been commercially implemented in a wafer-scale process [3]. Index guiding in the VCSEL structure is accomplished with 25nm deep, circular index guides that are etched into the surface of the top DBR prior to the second wafer bond. The index guides vary from 5 to 14μm in diameter.

The completed VCSEL array has lasing wavelengths of 1550 and 1530nm. Fig. 2 shows the power output versus pump power at room temperature of dual-wavelength, 14μm diameter devices. The peak output powers for the 1550nm and 1530nm lasers are 3.5mW and 1.7mW with respective thresholds of 0.6mW and 0.5mW (not shown). The difference in the performance of the devices is attributed to the 20nm difference between the PL peak and the cavity mode of the 1550nm device, a difference that favors lasing rollover at higher optical pump powers. Fig. 3 shows the 5μm devices operating in a single transverse mode with side-mode suppression ratios greater than 38dB.

We have shown the first application of nonplanar wafer bonding in the fabrication of a dual-wavelength VCSEL array with two different active regions. The devices exhibit single-mode performance and high multi-mode output powers. Nonplanar wafer bonding is a useful technique for the integration of differing semiconductor structures in the same plane of a wafer without degrading device performance.

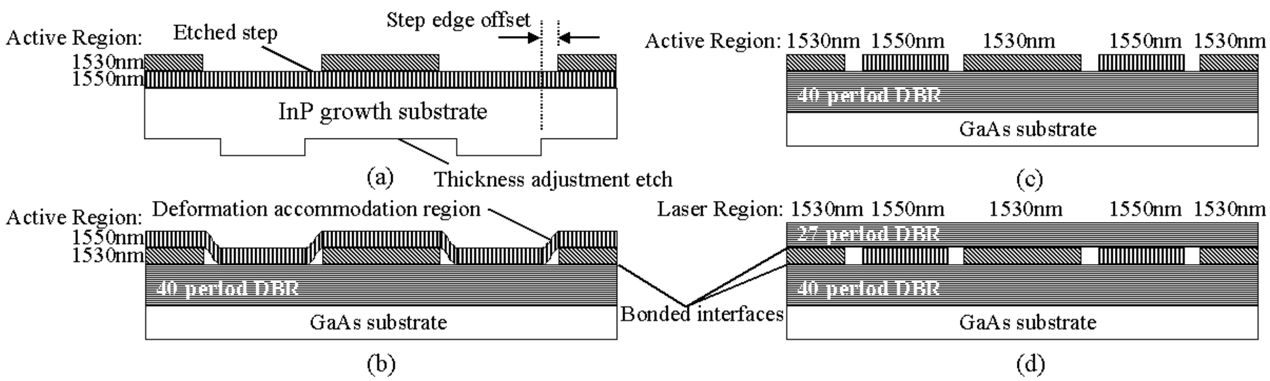

Fig. 1. Process flow cross-sections for fabrication of dual-wavelength VCSEL array

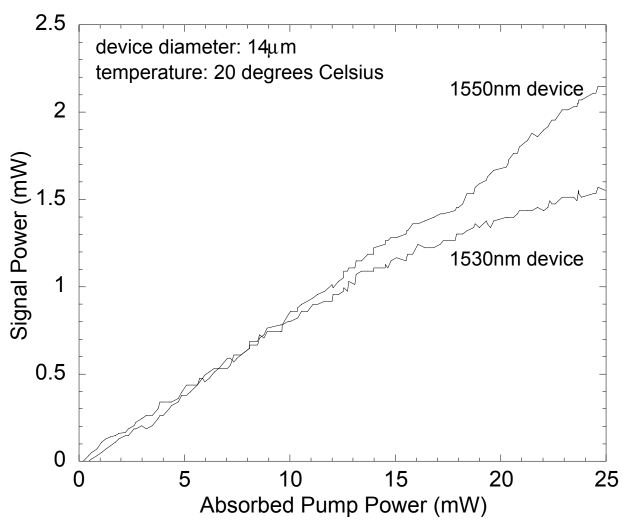

Fig. 2. Signal power verses absorbed pump power for the dual-wavelength VCSEL chip

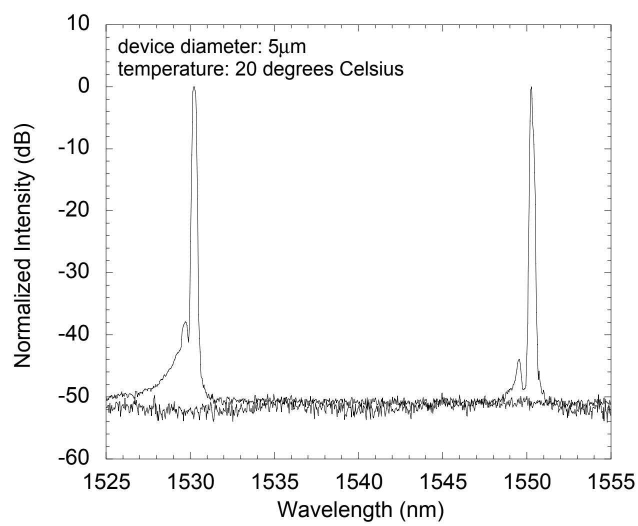

Fig. 3. Superimposed lasing spectra of dual-wavelength VCSEL chip

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